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Stormwater Management Study of the Redhill Creek Watershed City of Hamilton

Summary Report

Philips
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416 335 2353

April 27, 1983.
Our File 80046

Mr. Konrad Brenner, P. Eng.,
Regional Municipality of Hamilton-Wentworth,
Engineering Department,
City Hall, 71 Main Street West,
Hamilton, Ontario.
L8N 3T4

Dear Sir:

RE: Stormwater Management Study of Red Hill Creek Watershed

We are pleased to submit our findings on the Red Hill Creek Stormwater Management Study.

This report is a combined summary of the following two detailed technical reports

- Phase A: Stormwater Management Techniques
- Phase B: Watershed Modelling

This summary report is only intended to briefly describe the scope of the work and results obtained.

For a fuller description, reference should be made to the detailed technical reports named above and their supporting documentation.

Should you have any questions, please do not hesitate to contact us.

Yours very truly,

PHILIPS PLANNING + ENGINEERING LIMITED

Karen Dennison

Karen D. Dennison, P. Eng.,
Project Manager.

KDD/bls
Encl.

URBAN MUNICIPAL
JAN 9 19[illegible]
GOVERNMENT DOCUMENTS

STORMWATER MANAGEMENT STUDY
OF THE
RED HILL CREEK WATERSHED
CITY OF HAMILTON

SUMMARY REPORT

APRIL, 1983

PHILIPS PLANNING + ENGINEERING LIMITED
Consulting Engineers and Town Planners
Burlington, Ontario
L7R 3Y2

(Project: 80046)

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SUMMARY REPORT

1.0 INTRODUCTION

This report is a combined summary of two detailed technical reports produced during this study of the Red Hill Creek watershed. The Phase A report discussed various stormwater management techniques and the impacts of development both with and without controls on peak flows from small sites. The Phase B report presented the comprehensive watershed computer modelling which was carried out.

This summary report is only intended to describe briefly the scope of the work and present a few of the results along with the study conclusions and recommendations. For a full description of the work carried out and results obtained, reference should be made to the detailed technical reports and their supporting documentation.

1.1 Watershed Description

The Red Hill Creek watershed drains an area of 71.94 square kilometers located within the Regional Municipality of Hamilton-Wentworth. Portions of the following member municipalities, listed in order of relative area drained, lie within the watershed limits as depicted on Map No.'s 2a, 2b and 2c:

- City of Hamilton
- Town of Stoney Creek
- Township of Glanbrook
- Township of Binbrook

The creek originates on the Niagara escarpment through several tributaries, flows over the brink of the escarpment at several picturesque waterfalls and then through a deep valley to Windermere Basin where it empties into Hamilton Harbour very near the Q.E.W. Skyway bridge.

In our study, we have considered the main stream to be that branch which runs northerly from Rymal Road (Highway No. 53) to the conservation area at Albion Falls where it cascades over the escarpment. From here it flows through the King's Forest area, passes under the TH&B Railway then crosses Queenston Road and Barton Street before passing alongside the Regional sewage and water treatment plants which are located near its mouth at Windermere Basin.

A major portion of Hamilton, lying above the escarpment is drained by two large tributaries which flow in an easterly direction until they meet the main stream.

The first of these tributaries flows roughly parallel to Limeridge Road, passes the Ottawa Street landfill site and meets the main stream a short distance upstream from Albion Falls. This branch has recently been mainly converted to a large box culvert trunk sewer 5.5 m by 4.6 m (18 ft. by 15 ft.) constructed to facilitate the future development of the Hamilton mountain area.

The second major tributary above the mountain runs as a trunk combined sewer, easterly along Fennell Avenue then over the escarpment and along Greenhill Avenue. This area has been almost totally developed and sewered for many years and during dry weather conditions all flow goes from Greenhill Avenue north to the sewage treatment plant. However, during periods of rainfall, much of the flow is bypassed to the main stream of Red Hill Creek near Greenhill Avenue. In order to minimize the detrimental impacts of these bypasses, the Region is presently constructing a very large holding tank (90,800 m^3) or 73.6 ac-ft. known as the Greenhill Storage Facility. It is intended that excess flow will be temporarily stored here and then treated during times of low flow. It is only during periods of high flow that this storage tank would overflow to the creek. This would occur during a design storm event such as the 5 Year Storm, but even then a significant portion of the flow in the runoff hydrograph would be captured and later treated.

Another large tributary system lies to the east of the main stream with two branches, one of which originates in the "Satellite City" area of Stoney Creek. From here it flows to and over the brink of the escarpment at Felker's Falls, then under the TH&B Railway embankment (reaches 715 and 714) where it joins the other branch just downstream of Quigley Road. This other branch (Reach 713) flows alongside Albion Road and also crosses the TH&B Railroad. From here the combined eastern tributary (Reach 710) flows roughly parallel to the TH&B embankment a short distance westerly to the main stream.

Below the escarpment the creek and its easterly tributary flow through deeply incised valleys which are crossed by several high embankments, the greatest of which carries the TH&B Railroad. These embankments impound flood water during major runoff events and act as very effective flood control reservoirs to significantly reduce peak flood flows in the downstream reaches.

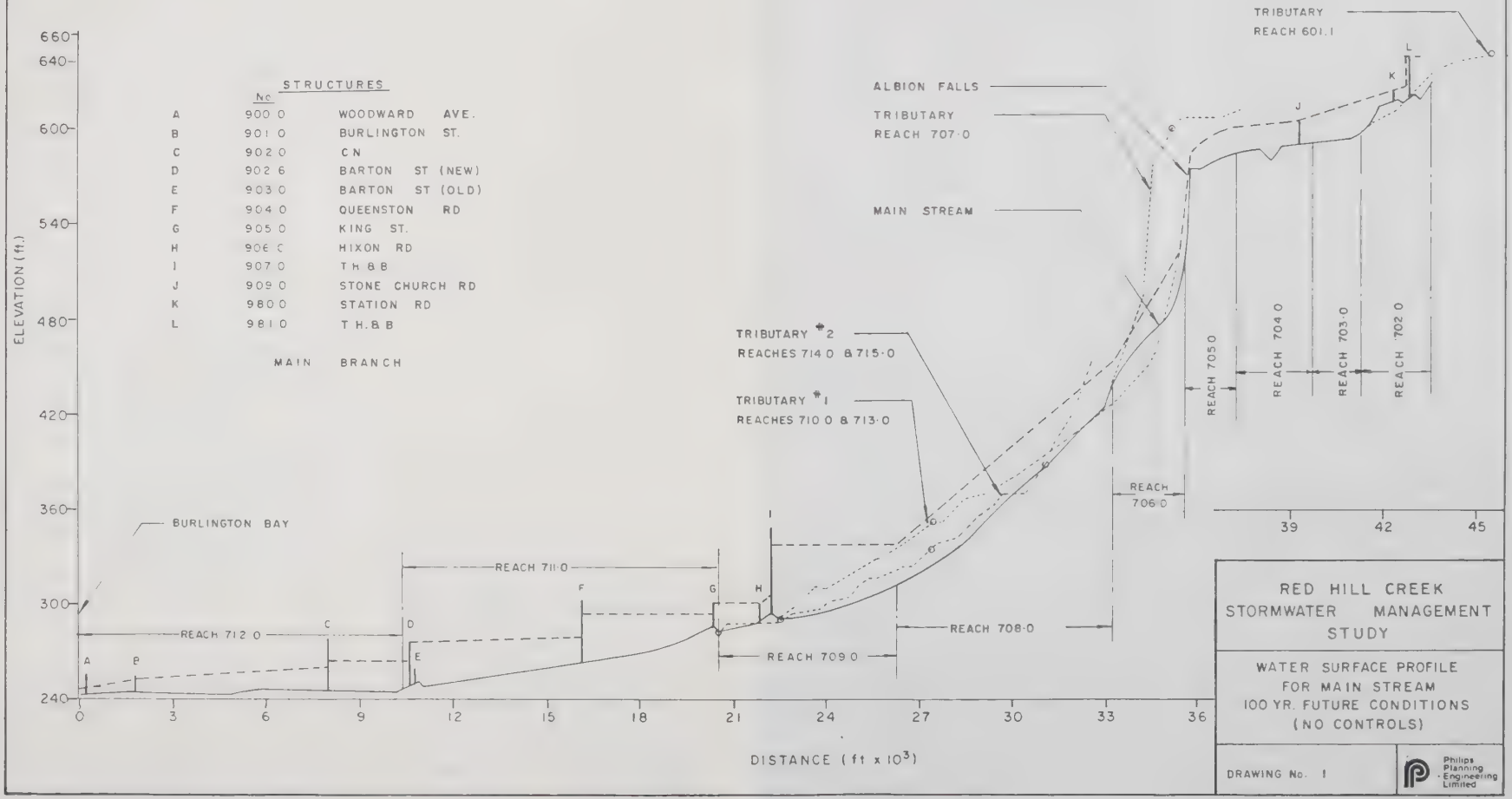
Profiles of the stream and its major tributaries may be found on Drawing No's. 1, 2 and 3 which follow. Map No's. 2a, 2b and 2c which follow depict the watershed modelling of the Red Hill Creek study area.

1.2 Stormwater Management: Qualitative Discussion

1.2.1 Overview

Stormwater management should not be thought of as being simply the controlling of runoff from development. In actual fact, the term is meant to refer to the whole process of planning and analysis of a watershed to arrive at specific objectives, followed by the imposition of runoff controls on development if necessary, in order to maintain the desired objectives.

When development is proposed, the impact of the development on the entire watershed should be analyzed for a full range of design conditions. Protective measures should then be applied as necessary, to either the watershed or the development, to ensure that future flooding and erosion problems are avoided. The practice of stormwater management rests on the premise that "an ounce of prevention is worth a pound of cure".



RED HILL CREEK
STORMWATER MANAGEMENT
STUDY

WATER SURFACE PROFILE
FOR MAIN STREAM
100 YR. FUTURE CONDITIONS
(NO CONTROLS)

DRAWING No. 1

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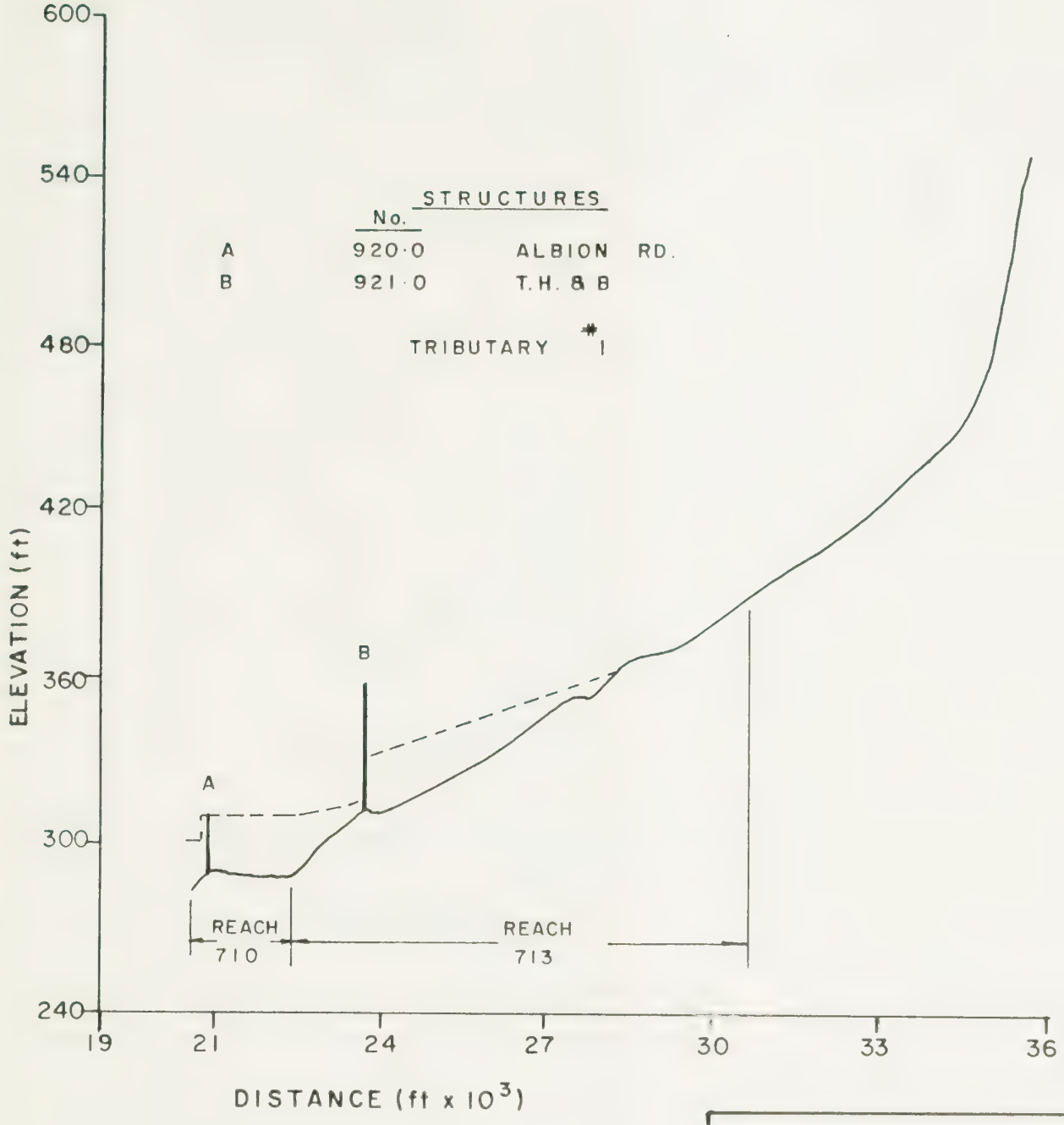

RED HILL CREEK STORMWATER MANAGEMENT STUDY

WATER SURFACE PROFILE
FOR TRIBUTARY # 1
100 YR FUTURE CONDITIONS
(NO CONTROLS)

DRAWING No. 2

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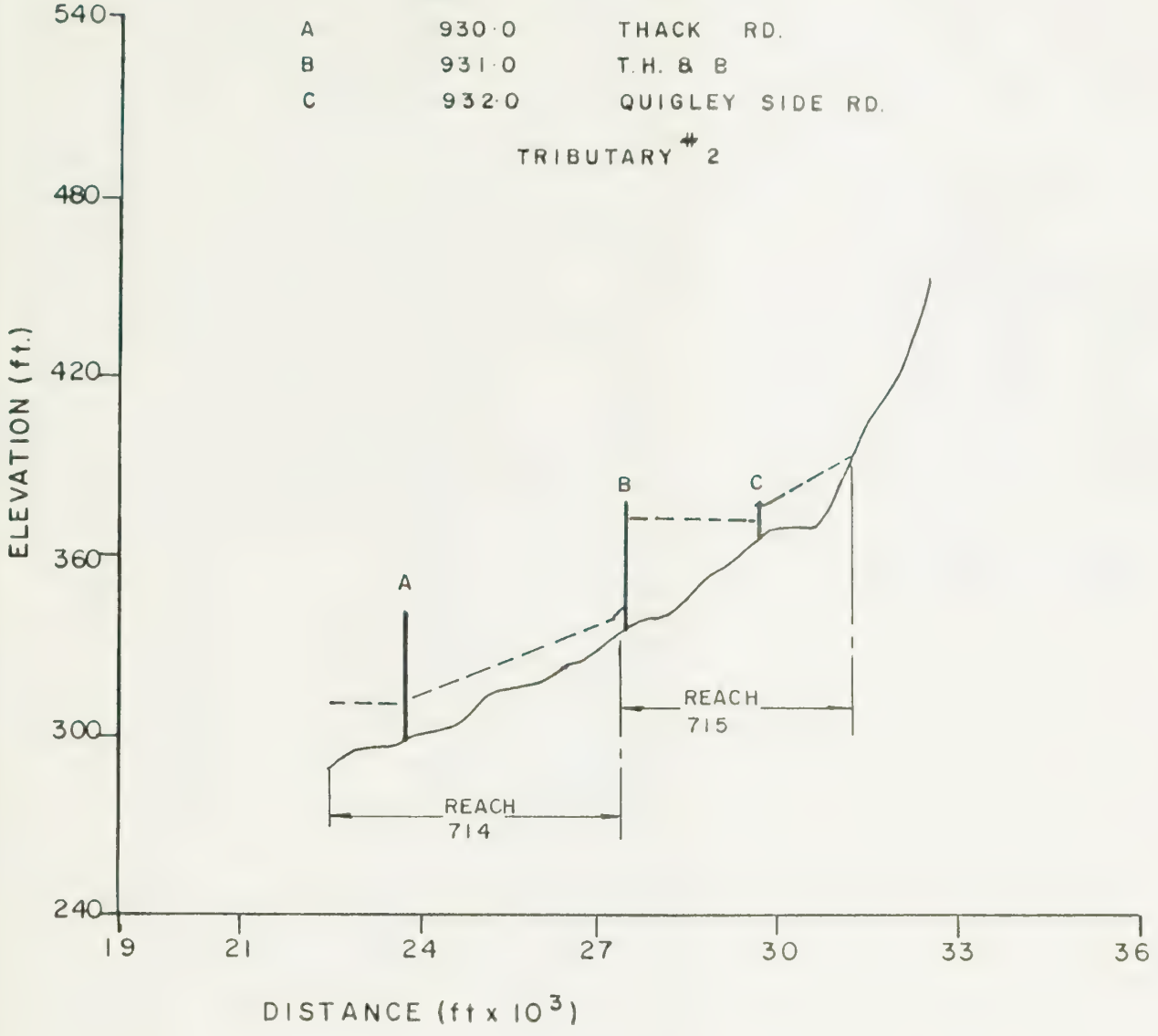
STRUCTURES

	No.	
A	930·0	THACK RD.
B	931·0	T.H. & B
C	932·0	QUIGLEY SIDE RD.

TRIBUTARY # 2



RED HILL CREEK STORMWATER MANAGEMENT STUDY

WATER SURFACE PROFILE FOR TRIBUTARY # 2 100 YR FUTURE CONDITIONS (NO CONTROLS)

DRAWING No. 3

Philips Planning Engineering Limited

LEGEND

- SUBCATCHMENT BOUNDARY
- 321 SUBCATCHMENT NUMBER
- ● 16 ROUTING NODE NUMBER
- 701 NATURAL STREAM ROUTING REACH
- 501 SEWERED ROUTING REACH
- 601 COMBINATION NATURAL STREAM AND SEWERED ROUTING REACH

RED HILL CREEK

STORMWATER MANAGEMENT STUDY

MODELLING LAYOUT OF STUDY AREA

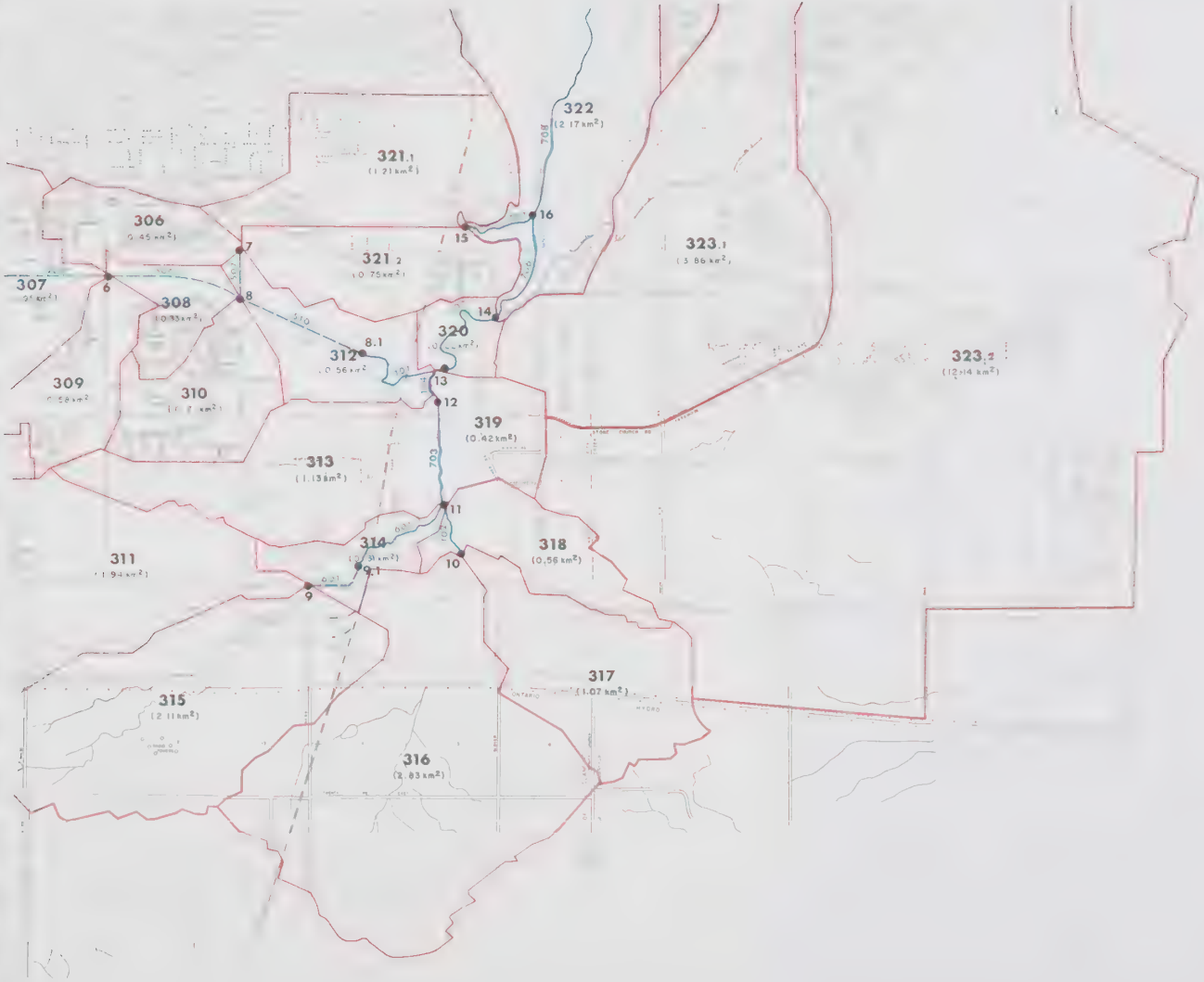
MAP 2A

LEGEND

	SUBCATCHMENT BOUNDARY
321	SUBCATCHMENT NUMBER
● 16	ROUTING NODE NUMBER
701	NATURAL STREAM ROUTING REACH
501	SEWERED ROUTING REACH
601	COMBINATION NATURAL STREAM AND SEWERED ROUTING REACH

RED HILL CREEK
STORMWATER MANAGEMENT STUDY
MODELLING LAYOUT OF STUDY AREA

MAP 2B



LEGEND

- SUBCATCHMENT BOUNDARY
- 321 SUBCATCHMENT NUMBER
- ● 16 ROUTING NODE NUMBER
- NATURAL STREAM ROUTING REACH
- SEWERED ROUTING REACH
- COMBINATION NATURAL STREAM AND SEWERED ROUTING REACH

RED HILL CREEK

STORMWATER MANAGEMENT STUDY

MODELLING LAYOUT OF STUDY AREA

MAP 2C

1.2.2 Hydrologic Impacts of Development

When a watershed is in a natural state, only a relatively small portion of rainfall from a normal storm will appear as surface runoff. Most of the rainfall on an annual basis will infiltrate initially. Of this initially infiltrated water, a sizeable portion on an annual basis will be used by vegetation and be given off as evapotranspiration. Most of the remainder will reappear as groundwater flow, sustaining watershed flow between periods of rainfall.

When development takes place on a watershed, most of the hydrologic impacts can readily be traced back to one cause: namely that infiltration is reduced.

Infiltration is reduced partly because of changing pervious landuse (e.g. woods to lawns) but mainly due to the reduction in pervious surfaces. The initial impact of reduced infiltration is greatly increased surface runoff with correspondingly higher peak flows. These higher flows have corresponding higher velocities and thus cause increased erosion. The erosion problems are greatly aggravated if high surface flows occur during the course of development, when large amounts of land may not have any ground cover.

A delayed impact of reduced infiltration is the fact that groundwater tables will be lowered since their source of input is reduced. Lowered water tables may lead to death of certain tree species and will certainly result in decreased base flow in the watershed. Decreased base flows lead to higher water temperatures, lowered water quality and the death of aquatic species. The construction of hydraulically efficient conveyance sytems (trunk sewers, lined channels) which frequently parallels development, also contributes partially to increased peak flow rates, since runoff velocities are greater and less storage is present.

These hydrologic impacts of development are depicted pictorially in Figures 1, 2 and 3 which were abstracted from reference 8.

FIGURE NO. 1

TYPICAL HYDROLOGICAL CHANGES DUE TO INCREASING IMPERVIOUSNESS

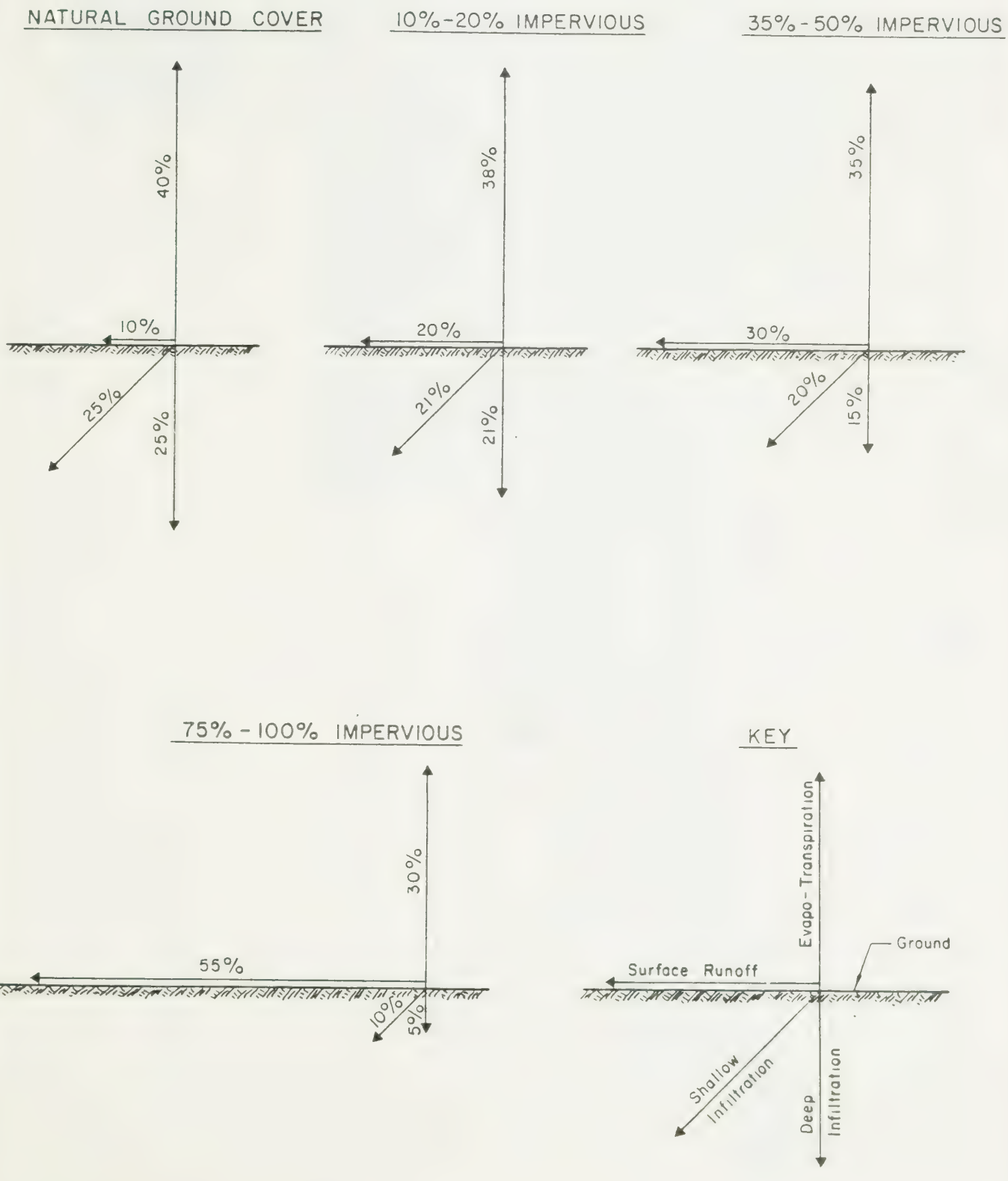


FIGURE NO. 2

EFFECT OF URBANIZATION ON MEAN ANNUAL PEAK FLOWS

(HATCHED AREAS INDICATE MOST COMMON MIX OF % IMPERMEABLE AND % SEWERED)

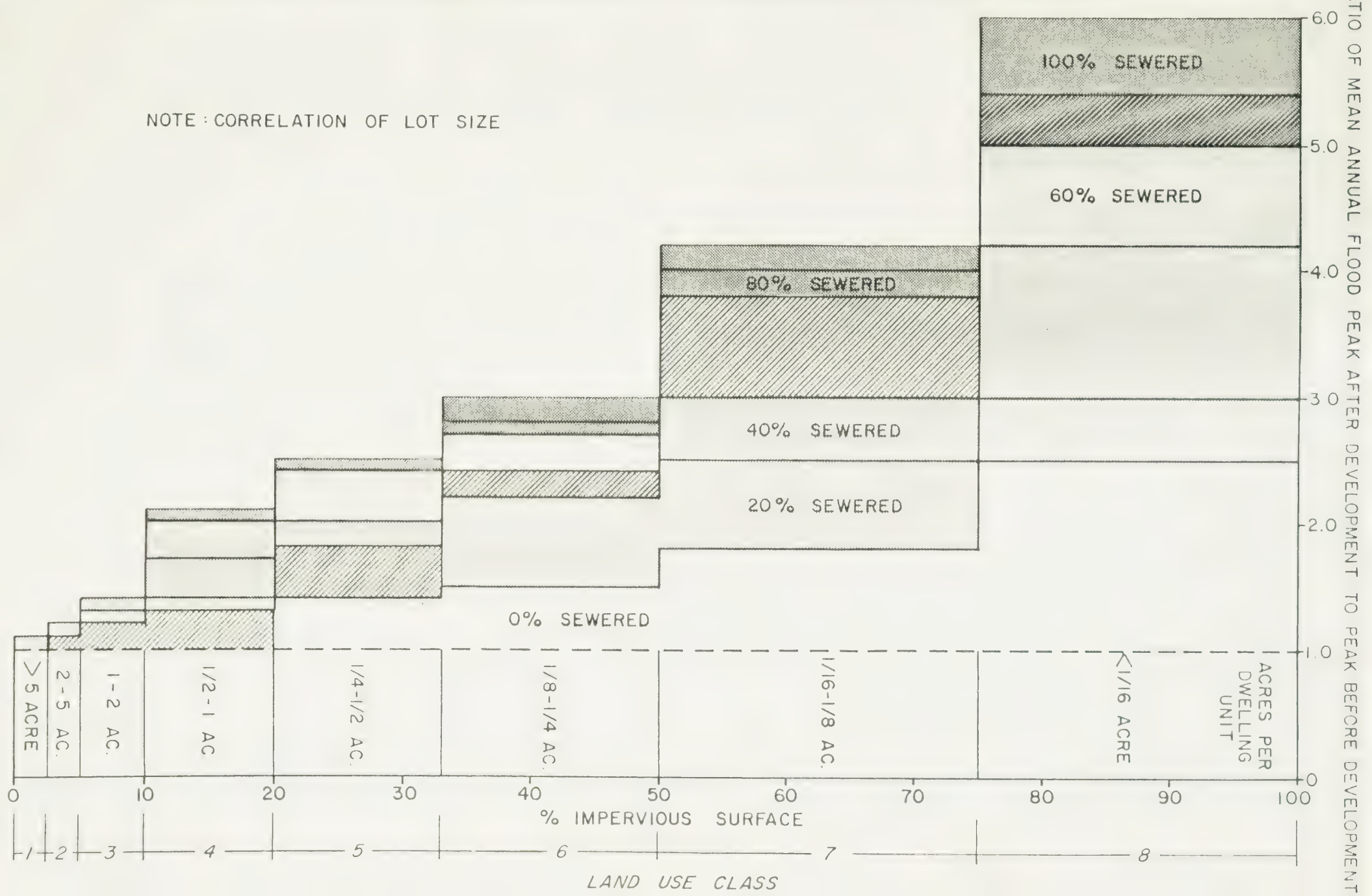
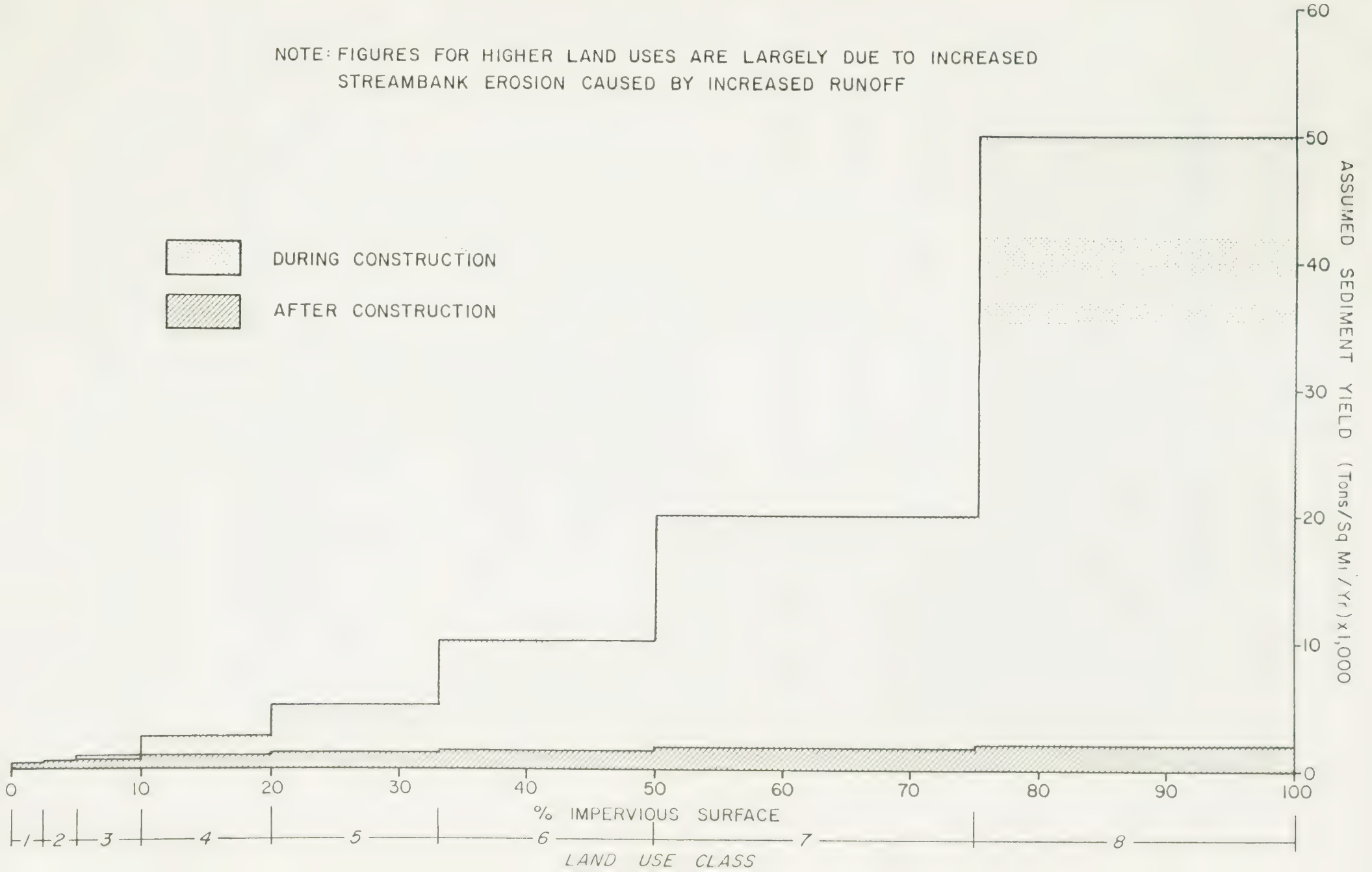


FIGURE NO. 3

EFFECT OF URBANIZATION ON SEDIMENT YIELD



1.2.3 General Stormwater Management Control Techniques and Their Heirarchy

There are many measures which can be taken to help control the increase in runoff due to development. The heirarchy of a number of these techniques is illustrated in Figure No. 4. This figure shows that controls may be implemented at various points along the runoff path, either singly or in conjunction with one another.

In general control techniques break down into the following two groups:

(a) measures to increase volume of infiltration

(b) measures to store water temporarily and spread increased volumes of runoff over a longer time period.

If, due to low average annual rainfall, hydrologic conditions in a watershed are to remain unchanged after development (stormwater management is undertaken), the pre-development split of rainfall into surface and subsurface flow must remain the same. This can only be done by maintaining infiltration volumes. Infiltration rates on pervious areas would have to be increased since some of the site will be covered by buildings and thus have no infiltration. If pre-development conditions are to be totally maintained, then infiltration rates on the remaining pervious area would actually have to increase to compensate.

Various techniques have been developed which aim to help maintain infiltration volumes after development. Some of these are dutch drains, french drains and other forms of seepage trenches, porous pavement and of course the disconnection of roof drains from sewers. Use of these types of techniques is probably the only way that pre-development hydrologic conditions can be maintained.

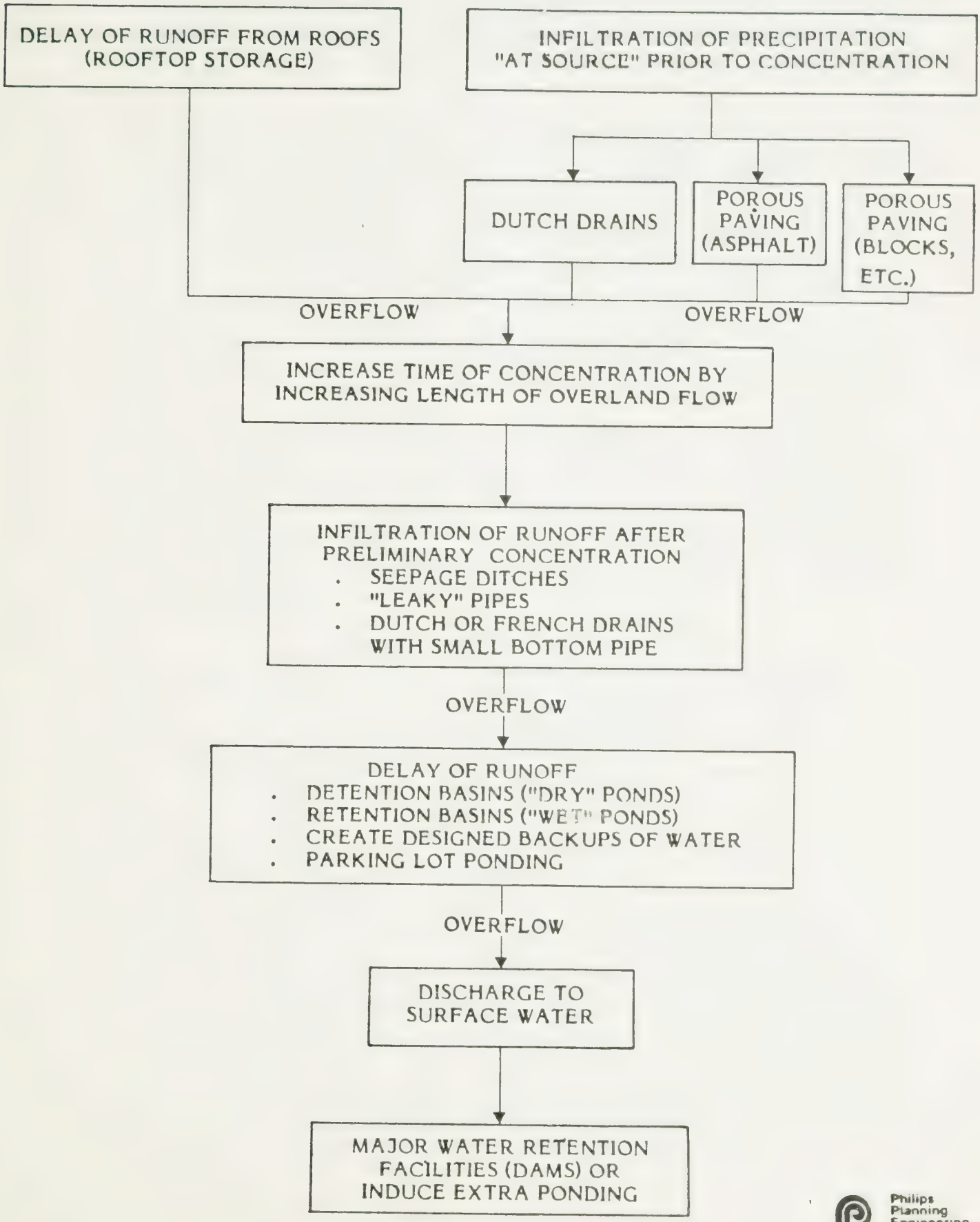
However, with the exception of disconnected roof drains, there may be a tendency for many of these control measures to "clog up" with silt and debris. If this were to occur it would be very difficult and expensive to correct at a

FIGURE NO. 4

HEIRARCHY OF

MEASURES TO CONTROL INCREASES IN RUNOFF

AND DECREASES IN INFILTRATION DUE TO URBAN DEVELOPMENT


DELAY OF RUNOFF FROM ROOFS (ROOFTOP STORAGE)
INFILTRATION OF PRECIPITATION "AT SOURCE" PRIOR TO CONCENTRATION
DUTCH DRAINS
POROUS PAVING (ASPHALT)
POROUS PAVING (BLOCKS, ETC.)
OVERFLOW
OVERFLOW
INCREASE TIME OF CONCENTRATION BY INCREASING LENGTH OF OVERLAND FLOW
INFILTRATION OF RUNOFF AFTER PRELIMINARY CONCENTRATION
. SEEPAGE DITCHES
. "LEAKY" PIPES
. DUTCH OR FRENCH DRAINS WITH SMALL BOTTOM PIPE
OVERFLOW
DELAY OF RUNOFF
. DETENTION BASINS ("DRY" PONDS)
. RETENTION BASINS ("WET" PONDS)
. CREATE DESIGNED BACKUPS OF WATER
. PARKING LOT PONDING
OVERFLOW
DISCHARGE TO SURFACE WATER
MAJOR WATER RETENTION FACILITIES (DAMS) OR INDUCE EXTRA PONDING

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later date. It would also be very difficult from an administrative point of view to keep track of all these installations. This is due to the fact that they are essentially "at source" techniques with installations located on virtually every lot.

Another class of control techniques, more suited to areas with higher average annual rainfall, seeks to change the shape of the post development runoff hydrograph. These techniques, on their own, do not help to decrease the volume of runoff, they simply help to "spread it out" over a longer period of time. With these techniques it is possible to keep post development peak flows equal to pre-development peak flows, but the post development peak flow will be sustained for a greater time period than the pre-development flow. These techniques seek to make more efficient use of downstream hydraulic capacity.

This is done by either the use of miniature flood control reservoirs such as retention ponds (wet ponds), detention ponds (normally dry), parking lot ponding, rooftop ponding and by increasing the length of the overland flow path. With the use of these techniques post development downstream flooding can be prevented but upper watershed low flows will still be much lower than before development.

When using these techniques to temporarily store runoff it is important to ensure that they are modelled on a watershed basis and not just on a site specific basis. It is very possible for post development peak flows to be equal to pre-development flows on a single site basis but for the total flows in the watershed still to be much higher than before development. This can happen if, by lagging of peak flows from each site, peak flows from certain areas reach the main stream simultaneously after development when they did not do so before. In this instance it would be better if one site received a bit more lagging and the other somewhat less. There is considerable potential for this type of occurrence on the Red Hill Creek watershed due to its several major tributaries. Another unfortunate consequence involving only one development, would be for a developer to expend a considerable effort on on-site detention only to have peak flows from his development now reach a major stream junction at the same time as peak flow from that tributary, when before they did not do so. In such a case, his effort would have been wasted.

Such occurrences can only be avoided if comprehensive watershed modelling by a review authority such as the City of Hamilton or the Hamilton Region Conservation Authority as appropriate is undertaken on the impacts of each development. It is somewhat impractical to carry out this type of monitoring, however, unless a complete watershed model is already set up for this purpose and can readily be run by members of the review authority's staff. Such a watershed model would have to consider unusual hydraulic effects such as those created by the many high embankments throughout the Red Hill Creek watershed. These embankments back up water acting similar to flood control reservoirs and have a pronounced impact on the timing of peak flows throughout the watershed.

From Figure No. 3 in Section 1.2.2, it can be seen that erosion can be a very significant problem during construction. This is largely due to the practice of clearing a site and leaving large areas without ground cover for a period of time. The best means of control is first to minimize the amount of land which is stripped at any one time and second to re-establish at least a temporary ground cover (e.g. seed and mulch) immediately. Various other sediment control techniques such as silt ponds (fairly good) and straw bale sediment traps may also be used. However, with soils having a very high silt content, (some of which are found in the Hamilton area), straw bale sediment traps can prove inadequate. The nearby Town of Ancaster has found silt washoff to be so high that straw bale sediment traps may be completely buried after a single severe storm. Silt ponds will work but may need to be re-excavated frequently following heavy silt washoff.

2.0 WATERSHED MODELLING

The watershed was broken down into 31 sub-areas in order that comprehensive hydrologic modelling of the watershed could be carried out. A greater level of detail was given to the area upstream of Albion Falls as it is this portion of the watershed within Hamilton which will experience the greatest changes due to development. This computer modelling took into account both major trunk storm sewer hydraulics and the impact of ponding behind existing embankments on flood flows. Reference should be made to the technical reports for details of this modelling.

The watershed was modelled for various design storms for the following conditions:

(a) existing conditions
(b) anticipated future land use as shown on Map Set No. 3 and assuming that present drainage policies are followed.

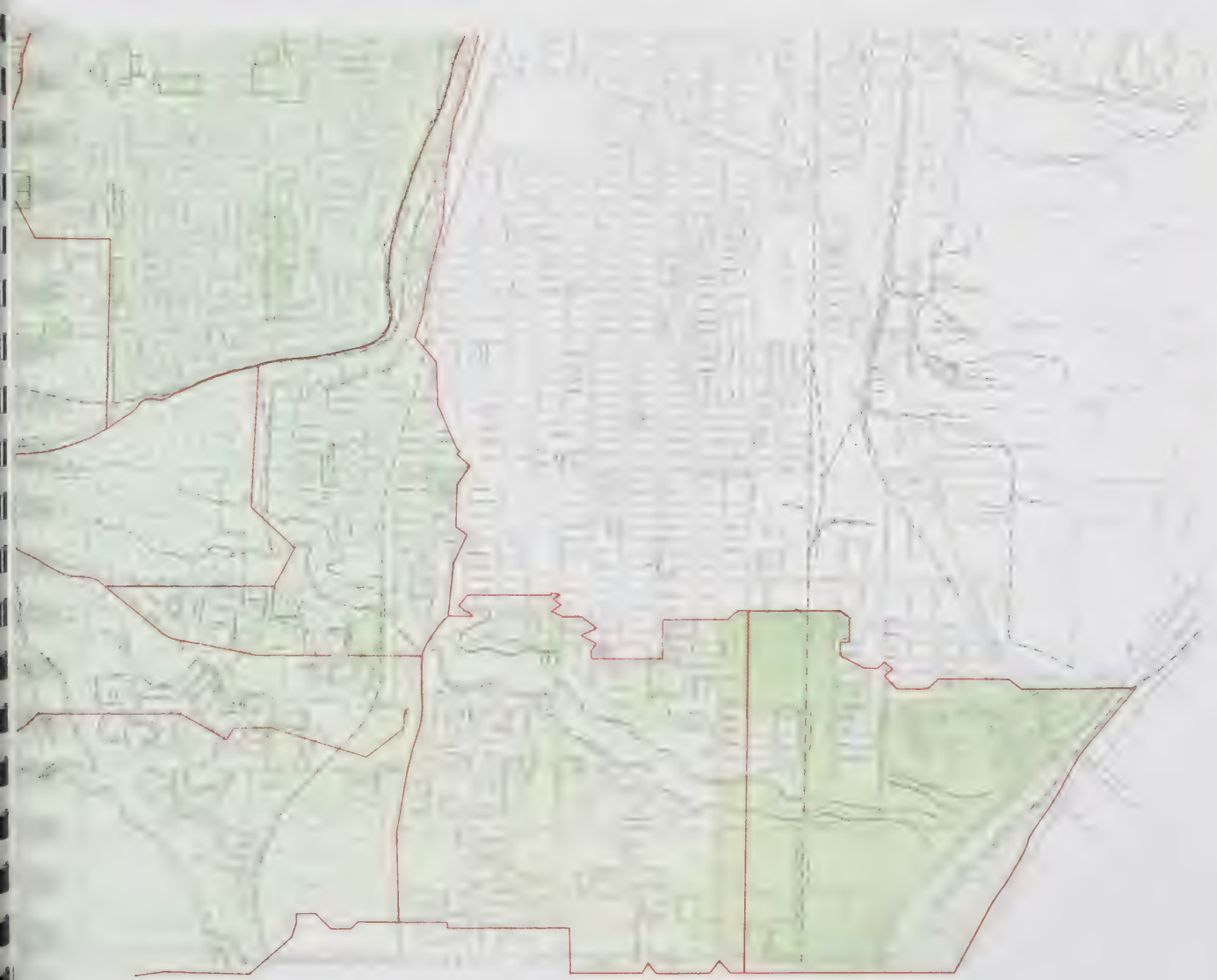
The impact of development on peak flows at a few selected points throughout the watershed is tabulated in Table No. 1, assuming that present drainage policies are followed (see Map 2 for locations of nodes).

2.1 Effect of Selected Stormwater Management Controls on Design Flows

2.2.1 Description of Stormwater Management Control

After discussions with the technical co-ordinating committee for this project about the results of modelling of future landuse conditions it was decided to simulate only the effects of agreed upon stormwater management techniques applied to the Glanbrook Industrial Area. For this area it was decided to test the effectiveness of requiring 2.54 cm (1 inch) of storage for all impervious areas in industrial landuses. The manner in which this amount of storage would be provided could vary from site to site and could involve such measures as:

- roof top storage (only get credit for 2.54 cm)



LEGEND

- AGRICULTURAL, OPEN SPACE & PARK
- RESIDENTIAL (low density)
- RESIDENTIAL (mixed density)
- RESIDENTIAL (high density)
- COMMERCIAL
- INDUSTRIAL

RED HILL CREEK

STORMWATER MANAGEMENT STUDY

FUTURE LANDUSE

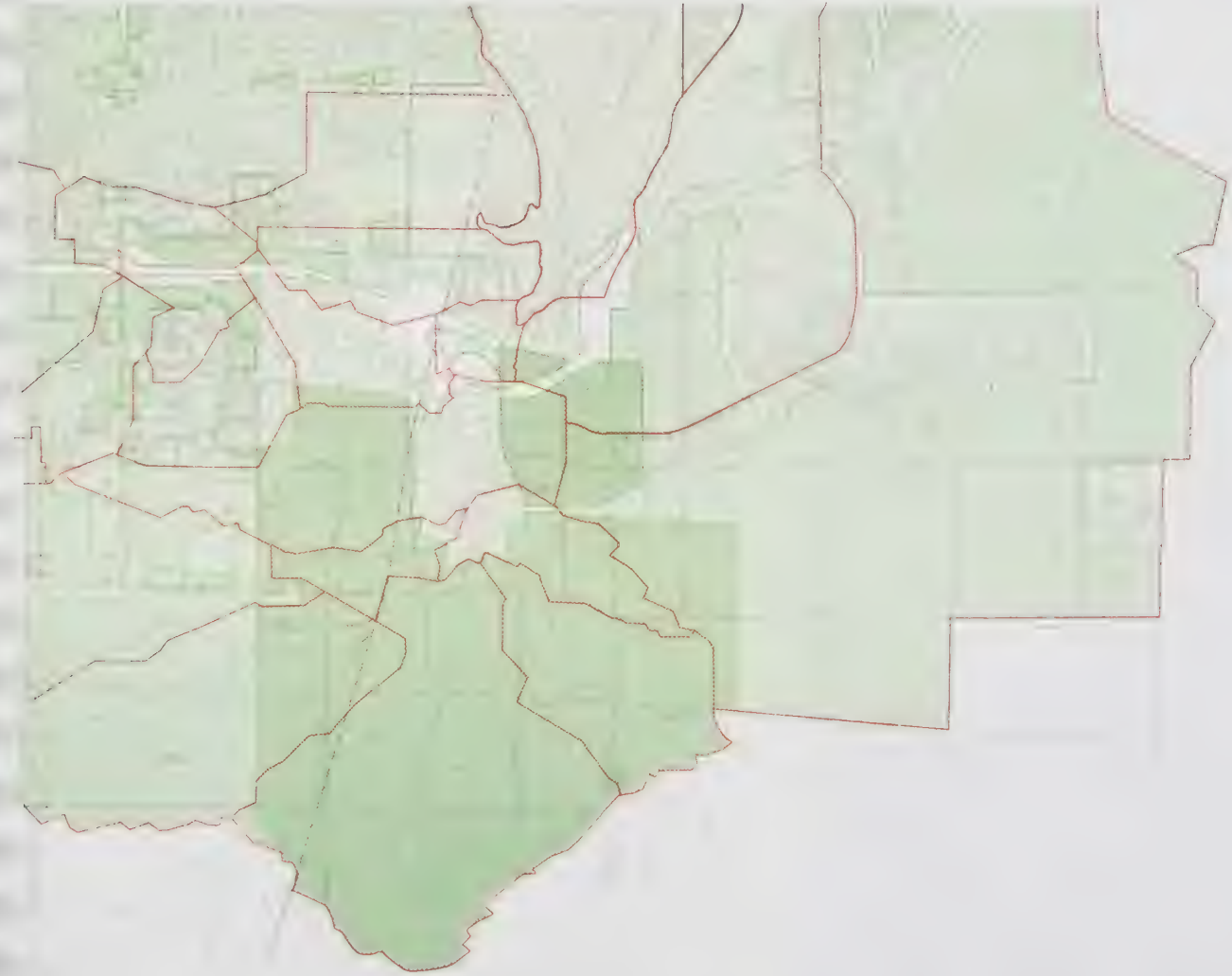
MAP 3A

LEGEND

- AGRICULTURAL, OPEN SPACE & PARK
- RESIDENTIAL (low density)
- RESIDENTIAL (mixed density)
- RESIDENTIAL (high density)
- COMMERCIAL
- INDUSTRIAL

RED HILL CREEK
STORMWATER MANAGEMENT STUDY
FUTURE LANDUSE

MAP 3B



LEGEND

- AGRICULTURAL, OPEN SPACE & PARK
- RESIDENTIAL (low density)
- RESIDENTIAL (mixed density)
- RESIDENTIAL (high density)
- COMMERCIAL
- INDUSTRIAL

RED HILL CREEK
STORMWATER MANAGEMENT STUDY
FUTURE LANDUSE

MAP 3C

TABLE NO. 1: EFFECT OF PROPOSED DEVELOPMENT ON PEAK FLOOD FLOWS

AT SELECTED LOCATIONS (NO RUNOFF CONTROLS)

LOCATION AND COMMENTS	% PEAK FLOW INCREASE WITH DEVELOPMENT			
	5 YEAR	10 YEAR	25 YEAR	100 YEAR
S. BRANCH ABOVE ESCARPMENT (NODE 11) - MAJOR LANDUSE SHIFT FROM RURAL TO INDUSTRIAL	601	443	418	283
W. BRANCH ABOVE ESCARPMENT (NODE 8.1) - MAJOR LANDUSE SHIFT FROM RURAL TO MIXED RESIDENTIAL	249	156	146	79
ALBION FALLS (NODE 14)	290	198	184	112
MAIN STREAM AT TH&B (REACH 709 OUTFLOW)	52	25	24	12
SMALLER EASTER TRIB. (REACH 713 OUTFLOW) - CONSIDERABLE SHIFT OF RURAL TO MIXED RESIDENTIAL	43	23	18	6
LARGER EASTERN TRIB. (REACH 714 OUTFLOW) - MAJOR LANDUSE SHIFT FROM RURAL TO MIXED RESIDENTIAL	102	51	42	19
TOTAL EASTERN TRIB. (NODE 21)	85	44	36	16
TOTAL WATERSHED JUST DOWNSTREAM OF LAST OF MAJOR TRIBUTARIES (NODE 22)	59	29	26	12
TOTAL WATERSHED AT MOUTH (NODE 24)	47	28	23	15

- parking lot storage
- detention ponds

In the SUBHYD program, depression storage is modelled with the use of Linsley's[1] exponential depression storage equation. With this equation, there is some immediate runoff but no significant amount occurs until all depressions are filled. For this reason, simply specifying a depression storage of 2.54 cm for impervious areas in SUBHYD, provides a reasonable modelling simulation of the desired control.

This 2.54 cm of impervious depression storage was specified for the following subcatchments: (see Map Set No. 2)

- 313
- 314
- 315
- 316
- 317
- 318
- 319

The watershed was then resimulated with the modified future conditions for the following design storms:

- 5 Year
- 25 Year
- 100 Year

2.2.2 Effect of Selected Industrial Stormwater Management Control

The effectiveness of requiring 2.54 cm of storage for all impervious areas in the Glanbrook industrial park is illustrated in Table No.'s. 12 and 13. Table No. 12 presents the results at a subcatchment level while Table No. 13 presents the results at selected points throughout the watershed. It can be seen from these tables that this stormwater management technique would greatly reduce the impact of the planned development on the watershed, although runoff from the area would still be considerably greater than under existing conditions. A greater degree of control could be attained by providing a larger amount of storage.

The amount of storage represented by 2.54 cm over all impervious surfaces in the Glanbrook industrial park is 136,000 m^3.

Alternatively, a flood control reservoir could be built at reach 704, upstream from Albion Falls. Such a reservoir would exert some control over almost all new development on the main stream upstream from Albion Falls and has previously been proposed.

Varying amounts of storage could be provided at this site depending on the depth of ponding as shown below:

POSSIBLE RESERVOIR STORAGE AT REACH 704

WATER LEVEL (feet)	STORAGE		SURFACE AREA		COMMENTS
	1000 m^3	Ac-Ft	Hectares	Acres	
600	145	117.9	10.7	26.4	- 0.5 m freeboard at Stonechurch Road - Ponding extended to about 150 m upstream of Stonechurch Road
605	372	302	19.3	47.6	- would have to raise Stonechurch Road by 1 metre at creek - ponding extended to about 460 m upstream of Stonechurch Road
610	729	592	26.5	65.6	- close Stonechurch Road between CNR tracks and Albion Road and block underpass under CNR - ponding extended to about 760 m upstream of Stonechurch Road (275 m downstream of Rymal Road).

TABLE NO. 12

EFFECT OF 2.54 cm IMPERVIOUS AREA STORAGE STORMWATER MANAGEMENT CONTROL FOR GLANBROOK INDUSTRIAL PARK AT A SUBCATCHMENT LEVEL

SUBCATCHMENT NO.	PEAK FLOWS								
	5 YEAR STORM			25 YEAR STORM			100 YEAR STORM		
	WITHOUT SWM	WITH SWM	% REDUCTION	WITHOUT SWM	WITH SWM	% REDUCTION	WITHOUT SWM	WITH SWM	% REDUCTION
313	27.5	11.4	58.5	42.9	25.5	40.6	58.1	44.0	24.3
314	8.75	3.57	59.2	13.6	7.97	41.4	18.2	13.7	24.7
315	40.1	15.5	61.3	62.4	35.8	42.6	84.1	62.8	25.3
316	78.5	29.9	61.9	120.3	67.7	43.7	159.1	117.1	26.4
317	31.9	12.5	60.8	49.0	28.2	42.4	65.2	48.5	25.6
318	14.0	5.83	58.4	21.9	13.0	40.6	29.8	22.5	24.5
319	10.8	4.76	55.9	15.1	10.7	29.1	19.0	16.1	15.3

TABLE NO. 13

EFFECT OF 2.54 cm IMPERVIOUS AREA STORAGE STORMWATER MANAGEMENT CONTROL FOR GLANBROOK INDUSTRIAL PARK AT SELECTED LOCATIONS THROUGHOUT THE WATERSHED

NODE NO.	PEAK FLOWS (m^3/s)								
	5 YEAR STORM			25 YEAR STORM			100 YEAR STORM		
	WITHOUT SWM	WITH SWM	% REDUCTION	WITHOUT SWM	WITH SWM	% REDUCTION	WITHOUT SWM	WITH SWM	% REDUCTION
9	71.8	47.2	34	112.4	85.7	24	152	131.2	14
10	110	42.4	61	169	95.9	43	224	165.7	26
11	115	63.6	45	168	114	32	224	181.0	19
13	187	149	20	273	241	12	352	318	10
14	186	148	20	274	237	14	354	315.8	11

3.0 CONCLUSIONS

Based upon the results of this Stormwater Management Study, the following conclusions may be drawn:

(1) Development will have a significant impact on the peak flows from a catchment. This impact will vary considerably depending on original landuse, storm size, type of development, and to a lesser degree, with the range of soil types and slopes found in the undeveloped portions of the Red Hill Creek watershed.

(2) The imposition of simple, at-source runoff controls such as disconnection of roof drains for residential areas, and rooftop ponding for industrial and commercial areas, can reduce the impact of development on peak flows considerably.

(3) Fully developing the presently undeveloped areas of the Red Hill Creek upstream from Albion Falls will dramatically increase peak flow rates at Albion Falls by a factor of 2.8 during a 25 Year Storm.

(4) The impact of future development on major flood flows will not be nearly as significant in the lower reaches of the creek because it will be largely "damped out" by ponding behind the TH&B embankment. The 25 Year Storm peak flow at the confluence of the main stream and eastern tributary, a short distance downstream from the TH&B embankment will only increase by a factor of 1.26. By the mouth of the creek this factor would be further reduced to 1.23.

(5) The most intense development is expected to take place in the Glanbrook Industrial Park. The impact of this development could be significantly reduced by the provision of on-site temporary storage equivalent to 2.54 cm over the entire impervious area. This would reduce the future 25 Year Storm peak flow by 30% to 40% from this area and the total 25 Year Storm peak flow at Albion Falls would be 14% less than otherwise.

(6) The TH&B embankment crossing the main stream and both major branches of the eastern tributary acts similar to a flood control dam which, if stable during such an event, would back water up greatly reducing peak flows.

(7) Although the TH&B embankment across the main stream was not overtopped during any of the simulations, its failure during a 100 Year Future condition storm event is quite possible. During this simulation water was ponded to a depth of 13.4 m behind the embankment, which represents 82% of the embankment's height, and is higher than the roofs of numerous homes located a short distance downstream. If the embankment were to fail during such an event, the consequences would likely be catastrophic. Just downstream from this embankment the creek has a 90° bend and during such a failure, flood waters would overtop the bank and likely wash away many of the homes located on Sinclair and Elaine Courts and flood numerous homes along Lawrence Road near King Street. Failure of the TH&B embankment during such an event would also likely lead to subsequent failure of the downstream crossings and considerable flooding at the sewage and water treatment plants located at the mouth of the creek.

The embankment would not have been designed to act as a dam but could be reinforced to be able to withstand safely such extreme ponding conditions. The stabilizing of this embankment as necessary would be very worthwhile since it acts so effectively as a natural flood control structure.

(8) Numerous locations and conditions of potentially erosive velocities were identified. The consequences of such velocities cannot be evaluated however without a comprehensive survey of the stream channel to establish permissible velocities along its length and to identify the extent and location of existing erosion protection works.

(9) The capacity of the various structures along the stream reaches modelled is adequate for existing conditions since during the 25 Year Storm condition only Hixon Road and the old Barton Street crossing would be overtopped. The Hixon Road structure is used at present only as a footbridge and the Barton Street crossing has been recently rebuilt just downstream from the old structure.

Under future 25 Year Storm conditions the following structures would be overtopped:

- C.N.R. culvert west of Dartnall Road
- Stonechurch Road
- Quigley Side Road

(10) The detailed watershed modelling carried out for this Study has demonstrated the following:

- due to the shape of the watershed (narrow in the lower reaches and flairing out in the upper reaches), and the low slopes and large storage volumes in the lower watershed, the peak flows in the watershed are greatest in the area of confluence of the major tributaries near the Greenhill Storage facility. Proceeding from this point downstream, the attenuative effects of valley storage more than compensate for the slightly increasing watershed area.

- The large embankments in the lower watershed have a very significant impact on peak flood flows.

Floodplain mapping for the watershed, which was done some time ago using techniques common at the time, considered the entire watershed simply as a single subcatchment, and did not consider these effects. Peak flows were estimated at the mouth of the basin and simply related to drainage area in other parts of the watershed. If the floodplain mapping were redone, with the level of detail considered in this study, significantly different results would likely be obtained. Such work should not at first assume that the embankments will fail as is commonly done. Rather it should determine the impact of the embankments on Regional Storm flood flows and levels and then establish what if anything, would be required to make the embankments stable. Then the cost effectiveness of stabilizing the embankments if and as necessary could be established versus the cost of alternative culvert replacements through the embankments and downstream channel improvements.

4.0 RECOMMENDATIONS

The following recommendations are respectfully submitted:

(1) Explicit design and provision of both major (or overflow) and minor drainage systems should be done for all new development. The minor and major systems should be designed to the 5 and 100 Year Storm level respectively. In drainage areas larger than 100 acres (40.5 hectares) a hydrograph method of analysis should be used so that the effects of ponding and detention storage can be analysed.

(2) Roof drains should not be connected to the sewer in the residential areas. They should discharge onto concrete splash pads located at ground level and lot grading should be such that roof drain flow will drain away from the building so that infiltration may occur.

(3) Provision of some form of temporary ponding should be made for all commercial and industrial developments. This may be done by a combination of rooftop ponding, parking lot ponding or detention ponds. Detention Storage equal to 2.54 cm for all impervious surfaces should be provided in new industrial development.

(4) Evaluation of proposed major and minor drainage systems, the effectiveness of controls and the hydrologic impact of specific developments should be carried out by a conceptual hydrologic simulation model.

(5) A comprehensive survey of the storm channels should be carried out to establish maximum permissible velocities at all locations. This work should be referenced to the existing floodplain mapping of the watershed. The results of this survey, when correlated with the results presented in Table Set. No. 4 in Appendix A of the watershed modelling technical report will allow a determination of the extent and severity of both existing and potential future erosion problems.

(6) Stability analyses should be carried out for the major embankments which pond water and tend to act as natural flood control reservoirs, effectively helping to control both existing and future flooding. The TH&B embankment which crosses 3 branches of the creek below the escarpment is most important from this point of view. Emphasis should be on taking what steps are necessary to ascertain that these embankments remain stable, rather than on increasing their capacity.

(7) The C.N.R. (west of Dartnall Road), Stonechurch Road and Quigley Side Road structures should be rebuilt with increased capacity to handle future flows. Rather than size these structures to pass all conceivable flows, provision shoud be made, where practical, to allow the structure to be safely overtopped during a major flood event.

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